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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
July 1940 as
Memorandum Report

EXPERIMENTAL INVESTIGATION TO DETERMINE THE RELATIVE MAGNITUDE OF VERTICAL AND HORIZONTAL GUSTS IN THE ATMOSPHERE

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WASHINGTON

L - 576

MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

EXPERIMENTAL INVESTIGATION TO DETERMINE THE RELATIVE MAGNITUDE OF VERTICAL AND HORIZONTAL GUSTS IN THE ATMOSPHERE

By PHILIP DONELY

Introduction

In the design of aircraft for the loads due to gusts encountered in flight, it is assumed that the gust is normal to the flight path of the airplane. The statistical data, reference 1, on which the design of aircraft for gust loads is based has been obtained for level flight and the gusts considered are vertical. When the flight path is vertical, as it is in some cases, the critical gust is horizontal and the question arises as to the relative magnitude and frequency of the vertical and horizontal gusts in the atmosphere.

General considerations indicate that a satisfactory procedure for the design of diving airplanes would be to assume the horizontal gusts to have the same magnitude and frequency distribution as the vertical gusts. This assumption yields satisfactory results at present but experimental verification of it would be desirable.

The purpose of the present investigation was to obtain data on the vertical and horizontal gusts in the atmosphere by reworking accelerometers and airspeed records from past investigations of vertical gusts. As the data was to be used for purposes of comparison, only about one fourth of tha available records were to be used in order to reduce the amount of work involved.

The records which form the basis of this investigation were obtained from fifteen flights of the XBM-1 airplane during gust surveys of cloud formations up to altitudes of 15,000 feet and from fifteen flights of the Aeronca, C-2N airplane, in clear air at altitudes less than 3,500 feet. All records were obtained in the vicinity of Langley Field, Va., during the period from January 1937 to August 1938.

Apparatus

The airplanes, used to obtain the records, were the Martin XBM-1 and the Aeronca, C-2N. Table I and reference 2 give the pertinent information on the two airplanes.

The instruments used in the airplanes were:

NACA airdamped accelerometer
NACA airspeed recorder
NACA synchronizing timer

The airspeed recorder and accelerometer were equipped with magazine type film drums with a capacity of 20 feet of film. A film speed of 1/8 inch per second permitted 30 minutes of record on the XBM-1, while a film speed of 3/8 inch per second gave 10 minutes of available record on the Aeronca, C-2N.

The method of evaluating the airspeed and accelerometer records to obtain the intensity of vertical gusts, U_{true}, has been developed in the past few years from the theory given in reference 1. The method consists of calibrating the reactions of an airplane to a gust of known shape and intensity by tests of a dynamically scaled model in the gust tunnel. A calibration factor is thus obtained which is dependent only on the gust size as defined by the gradient distance, H (reference 1), and which when divided into the measured acceleration increment gives the acceleration increment which would be computed if the true gust velocity, U_{true}, had been used in the well known sharp edged gust formula.

In practice, the gust tunnel tests are made for three gust shapes (reference 2), for gusts which have a lateral extent, greater than the span of the airplane model, and for conditions where the airplane travels from smooth air into a single gust. This means that the evaluation of flight records must be made for these conditions or the "calibration" will not give the correct value of U_{true}. At present, due to limitations of the records, it is necessary to assume that the atmospheric gust covers the entire span of the airplane while the second condition required above is satisfied by evaluating those gusts which the accelerometer record indicates have been preceded by smooth air.

The method of evaluating the records to obtain the horizontal gust velocity, ΔV, was simply to measure sudden changes in the recorded airspeed. (A sudden change was considered as one which took place in less than one second.) This procedure is based on the assumptions that the ground speed of an airplane will not change appreciably in a short period of time if the speed of the surrounding air changes and that the gust to be measured has no vertical component. A simple calculation indicated that the effect of the first assumption would be to reduce the indicated gust velocity about 7 percent. The second assumption was utilized as a restriction on the data in that only those portions of the airspeed records were used which were indicated by the corresponding section of the accelerometer record to be affected by small vertical gust components.

Results

The records from fifteen flights for each airplane were evaluated to obtain the vertical and horizontal gust velocities by the methods previously described. The number of vertical gusts evaluated was 2388 for the XBM-1 and 956 for the Aeronca C-2N. The horizontal gusts, evaluated from the same set of records, amounted to 1174 for the XBM-1 and 1429 for the Aeronca C-2N. These data were used to make the frequency curves, given in figures 1 to 4, of U_{true} and ΔV for each airplane.

In order to obtain a more convenient comparison of U_{true} and ΔV, the data in figures 1 to 4 were used to make cross plots of U_{true} against ΔV at equal frequencies for the two airplanes. These results are shown in figures 5 and 6.

Precision

The precision of measurement of U_{true} and ΔV is estimated to be within ±2 feet per second, if the precision of instruments and the method of evaluation are considered. Such an error is random and its effect on the shape of the frequency curves will be negligible for the purpose of this report.

One error, which will be of great importance relative to the shape of the frequency curves and the conclusions drawn, is that due to variations in the lateral extent of the gusts. In the case of vertical gusts, the method of evaluation assumes that the entire span of the airplane is covered and, since gusts may be smaller than the span of the airplane, the values of U_{true} computed will be either correct or too low, but never too high. This error will tend to shift the frequency curves towards zero gust velocity for U_{true}. The data for ΔV are not affected by this type of error since no assumption is made as to the lateral extent of the gusts. This means, therefore, that the frequency curve for ΔV will tend to be obtained in its true form and the comparison of U_{true} and ΔV will indicate that ΔV is larger than U_{true}.

Another factor, which will influence the results, is the amount of data obtained to form each frequency curve. The effect of having more data for U_{true} than ΔV will be to emphasize the discrepancy previously discussed, while it is probable that, if the relative amounts of data are reversed, it will tend to cancel this error. If this is so, the data for the Aeronca airplane should tend to show equality between U_{true} and ΔV as compared to the data for the XBM-1 airplane.

There appears to be no practical way of determining these errors for the present data, so that it will be necessary to deal with trends with these points in mind in order to use the data.

Discussion

The data from the tests on the Aeronca C-2?, figure 6, where the horizontal outnumbered the vertical gust gives almost a 45 degree line for U_{true} against ΔV which is displaced about one foot per second along the abscissa ΔV. For the tests on the XBM-1 airplane, figure 6, the vertical gusts outnumber the horizontal gusts about 2 to 1, and at low gust velocities ΔV is about 2 feet per second greater than U_{true} while the two tend to become equal for high gust velocities. As pointed out under precision, the errors in the data will tend to produce this result. It appears reasonable, therefore, to say that U_{true} and ΔV are of equal intensity and that the indications of the data have been modified by the limitations of the experimental data.

The discrepancy in the amounts of data for the variables considered is quite interesting and worth further consideration. The method of evaluating the records was identical for both airplanes so that the trends in the amounts of data obtained should be due to the flight conditions for the most part. In the case of tests with the XBM-1, the turbulence measured was due, primarily, to thermal currents and it might be expected that more vertical than horizontal gusts would be encountered. The Aeronca C-2N airplane was flown at low altitude in "wind" turbulence and hence it might be expected that the influence of the earth would tend to restrict the vertical motion of air so that the number of horizontal gusts would be larger. The data collected in the present investigation tend to bear out this reasoning and would tend to indicate that atmospheric turbulence is seldom isotropic.

Concluding Remarks

The results of this investigation indicate that the vertical and horizontal gusts are of about equal intensity in the atmosphere.

The data also indicates that, under thermal conditions, more vertical than horizontal gusts would be expected, while under conditions of wind turbulence, the relation is reversed.

The investigation also emphasizes the necessity of obtaining more information on the size of gusts with particular reference to the lateral extent of the gusts relative to the span of an airplane.

Langley Field, Virginia,
July 15, 1940.

REFERENCES

1. Rhode, Richard V.: Gust Loads on Airplanes. S.A.E. Trans., vol. 32, 1937, pp. 81-88.

2. Donely, Philip and Shufflebarger, C. C.: Tests in the Gust Tunnel of a Model of the XBM-1 Airplane. NACA TN No. 731, 1939.

Table I

Airplane Characteristics

Airplane	XBM-1	Aeronca
Weight, lbs.	5200	782
Wing Area, sq. ft.	412	144
Wing Loading, lbs./sq.ft.	12.6	5.44
Span, ft.	41	36
Mean Aerodynamic Chord, ft.	5.05	4
Slope of Lift Curve, per radian	4.5	4.7

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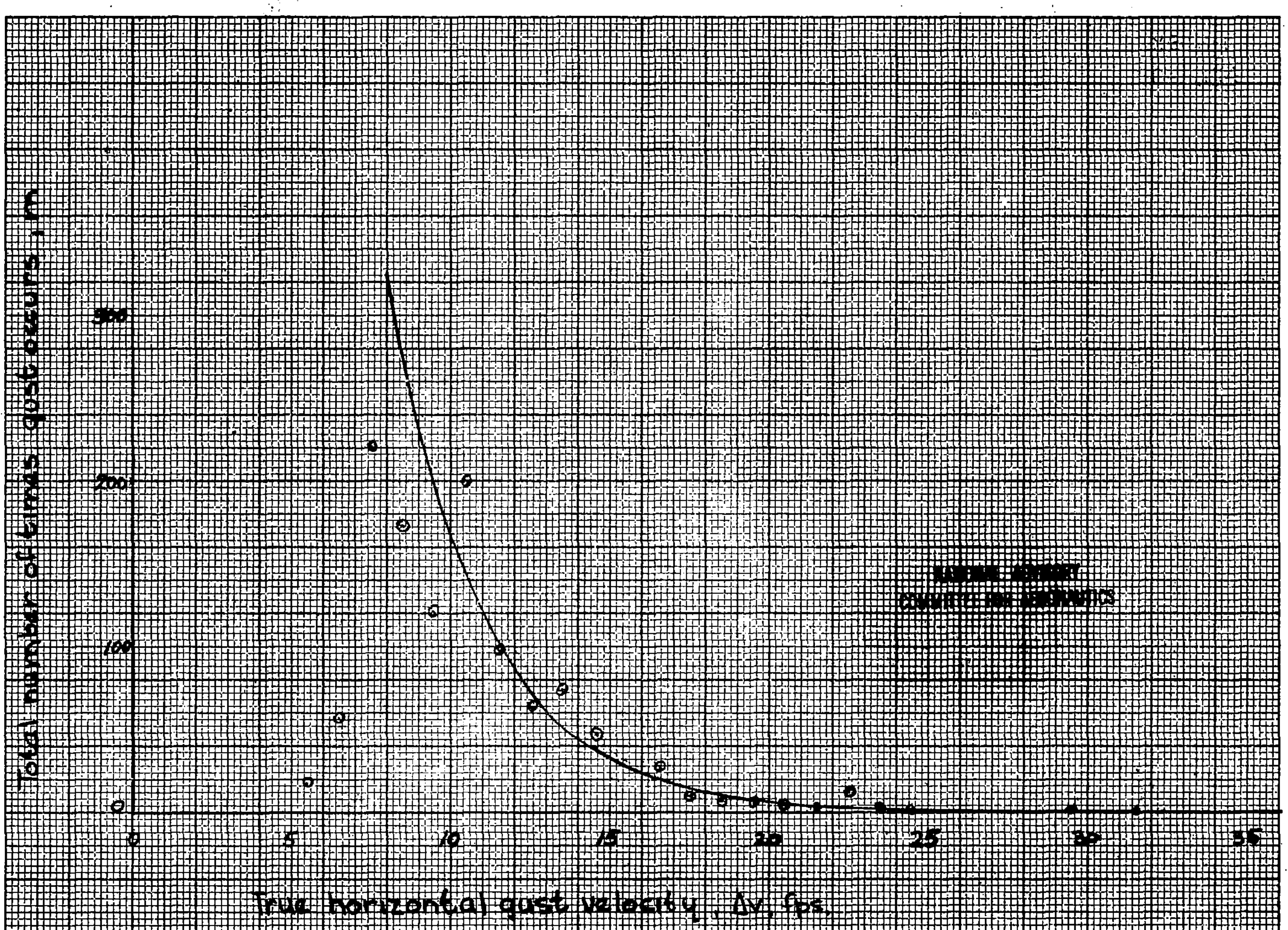

Figure 1 Frequency curve for horizontal gusts ΔV, for XBM-1
(Total number of gusts, n=1174)

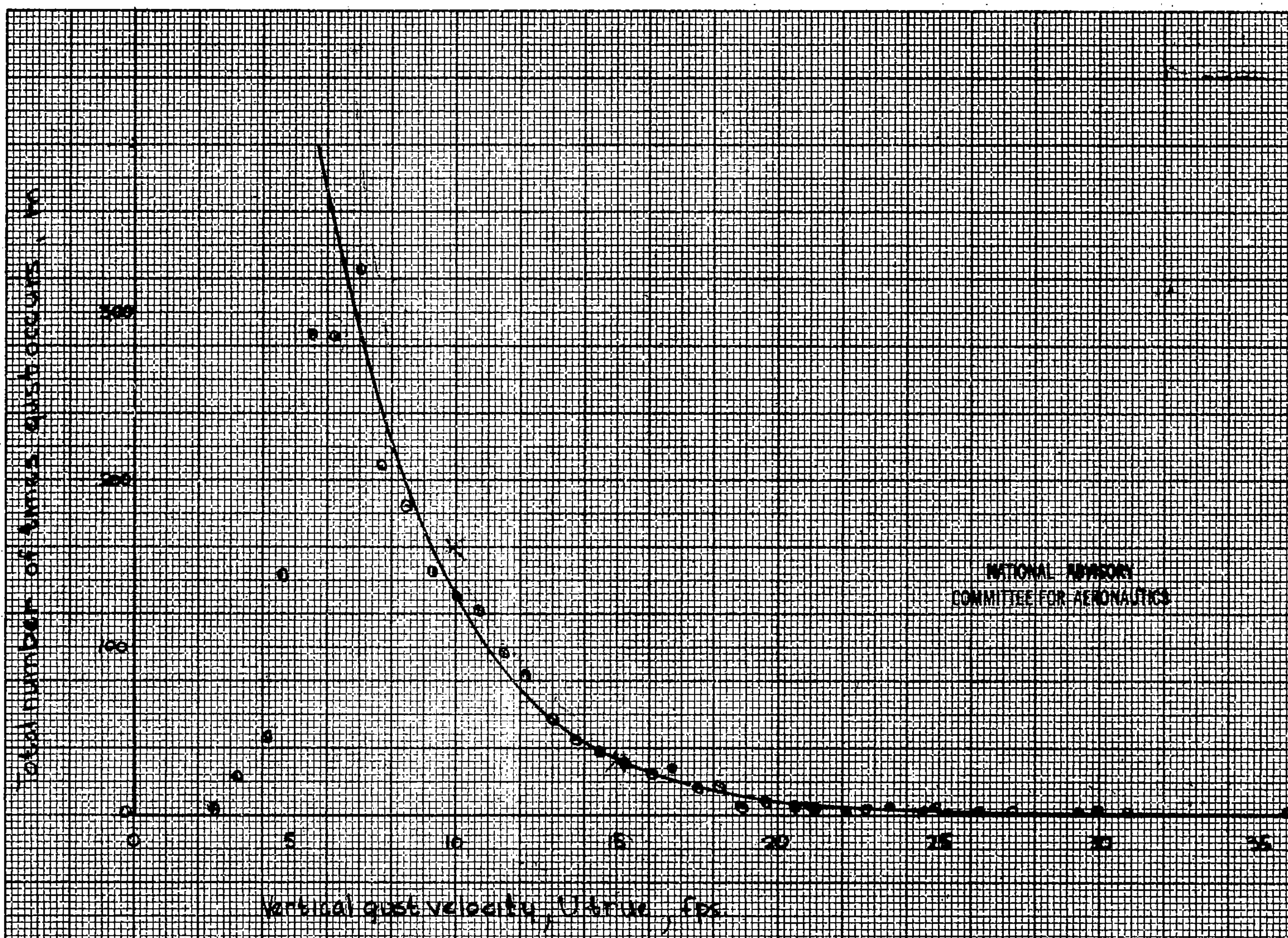

Figure 2. Frequency curve for vertical gusts U_{true} for XBM-1
(Total number of gusts, n=2388)

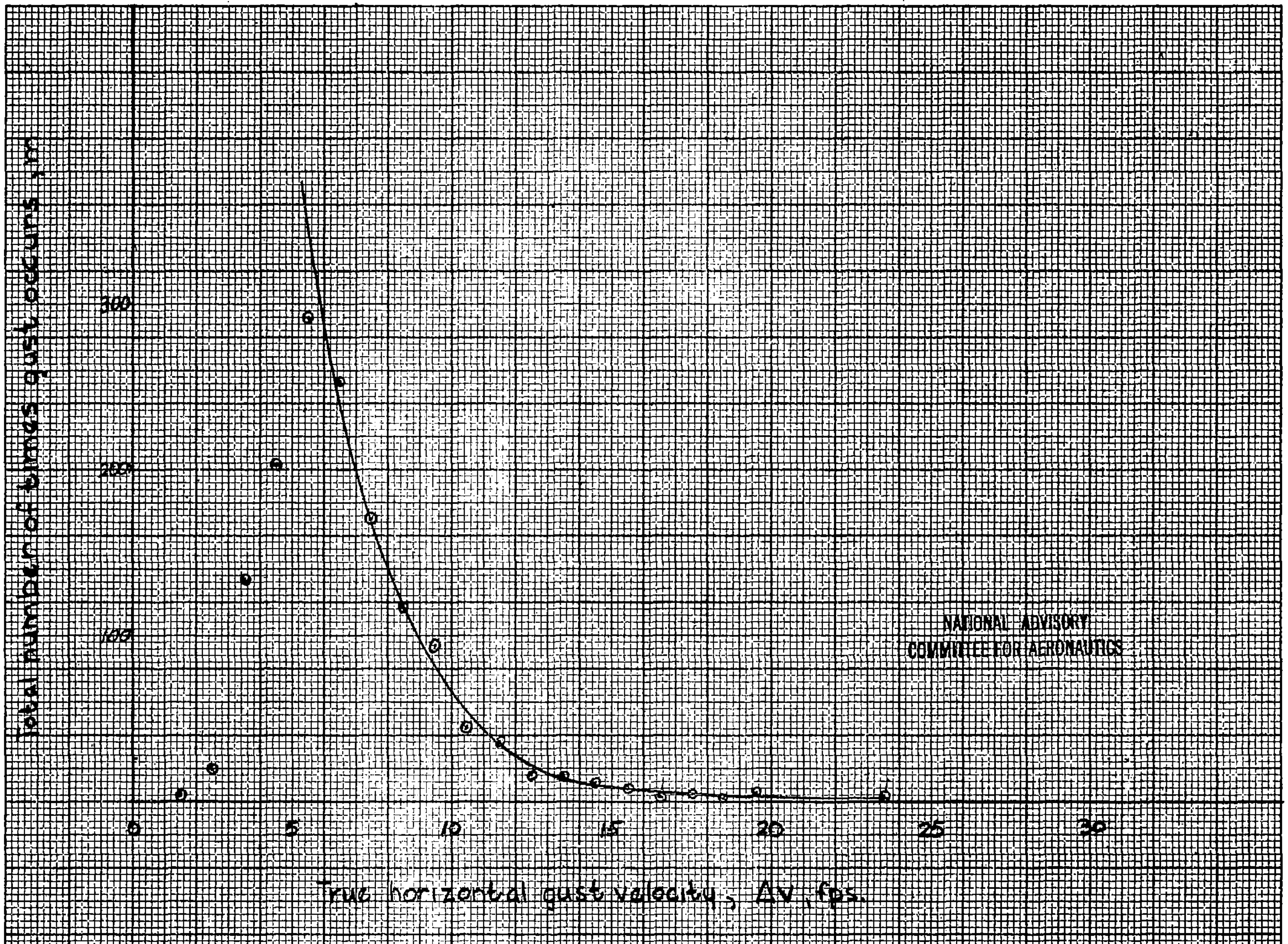

Figure 3. Frequency curve for horizontal gusts, ΔV, for Aeronca C-2N.
(Total number of gusts, n = 1429)

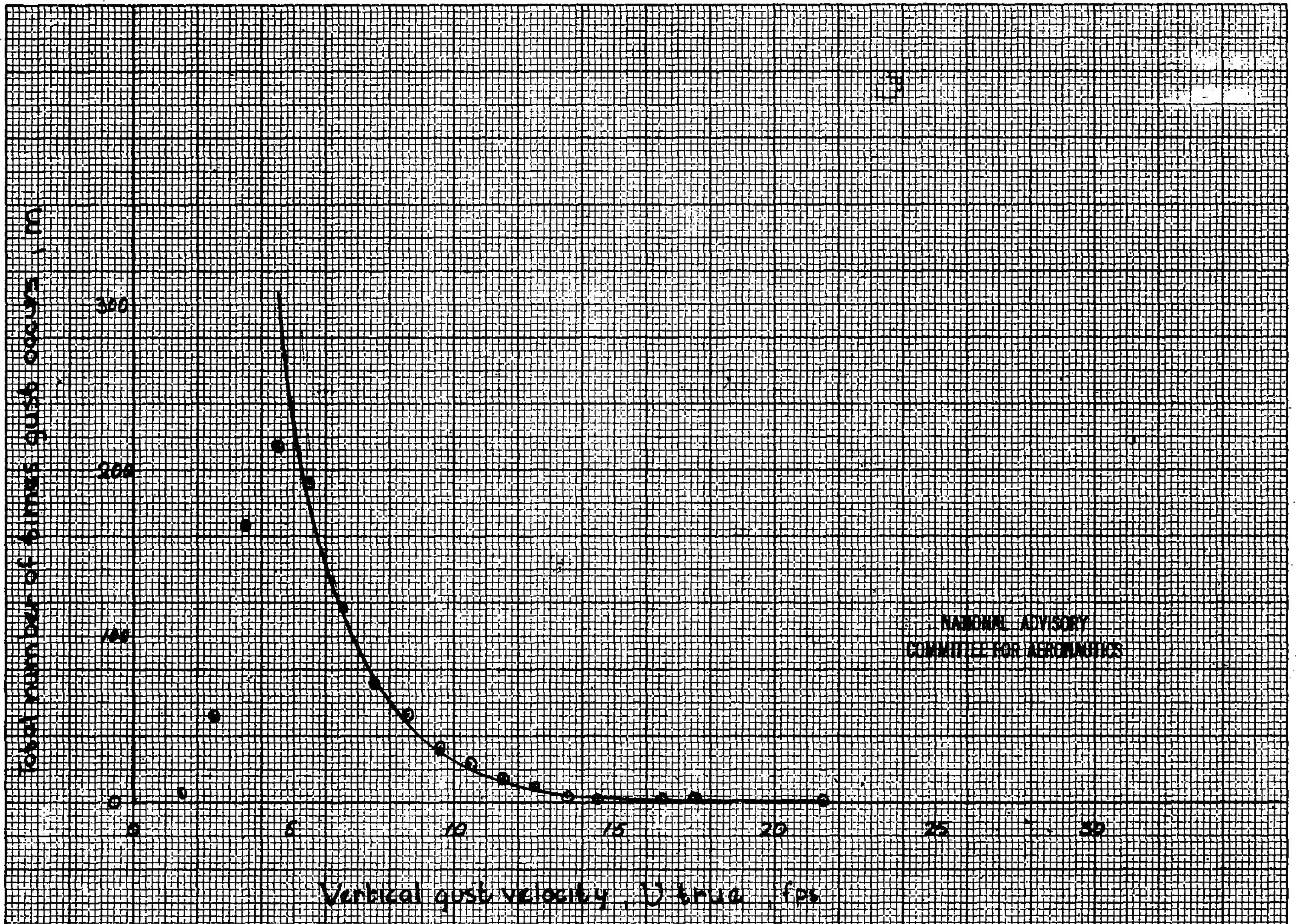

Figure 4. Frequency curve for vertical gusts, U_{true}, for Aeronca, C-2N.
(Total number of gusts, n=956)

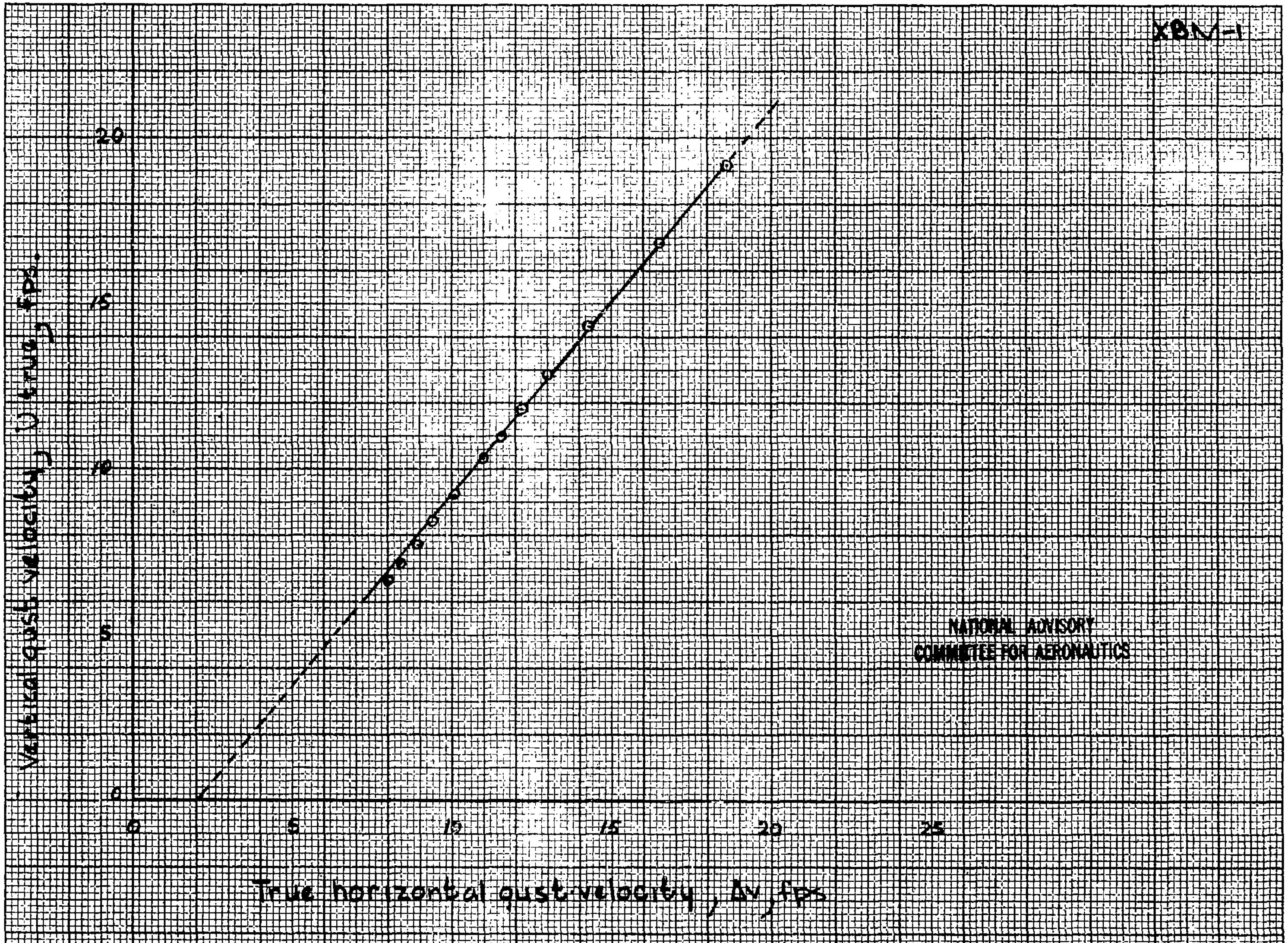

Figure 5. Variation of U_{true} with ΔV for equal frequencies for XBM-1.

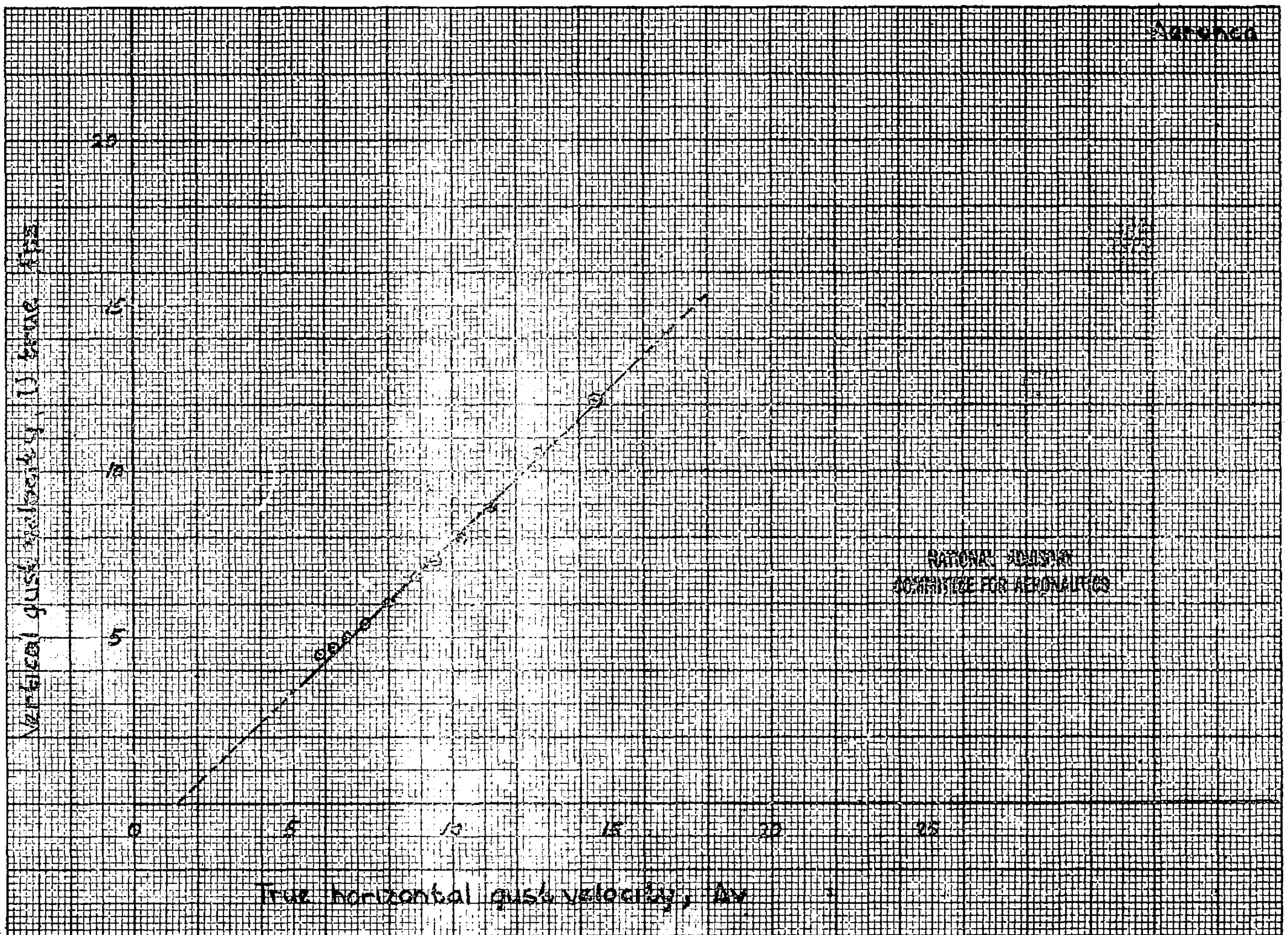

Figure 4 Variation of U_{true} with ΔV for equal frequencies for Aeronca, C-2N